Constraining ΔG with Double Helicity Asymmetry Measurements at PHENIX

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DIS 2010

Outline

- ΔG
- Polarized protons at RHIC
- The PHENIX detector
- Double Longitudinal Spin Asymmetries
  - Charged Pion
  - Direct Photon
  - Neutral Pion
- Global Fits, extracting ΔG
- Conclusion

ΔG

- Motivation: Better understand the proton spin, specifically the gluon contribution:

$$S_p = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

Where ΔG, the gluon contribution to the proton spin, is given in terms of Polarized Parton Distribution Functions (polarized PDFs)

$$\Delta G = \int_0^1 dx \Delta g = \int_0^1 dx [g_+(x,\mu^2) - g_-(x,\mu^2)]$$

Polarized Protons @ RHIC

- Polarized PDFs show up in differences of helicity dependent cross sections, e.g. in $\vec{p}+\vec{p} \rightarrow C + X$:

$$d\Delta\sigma = \sum_{a,b,c} \int dx_a \int dx_b \int dz_c \Delta f_a(x_a,\mu)\Delta f_b(x_b,\mu) D_c^C(z_c,\mu') d\Delta\hat{\sigma}_{ab}^c(x_a P_a, x_b P_b, P_C/z_c, \mu, \mu')$$

partons a+b → c

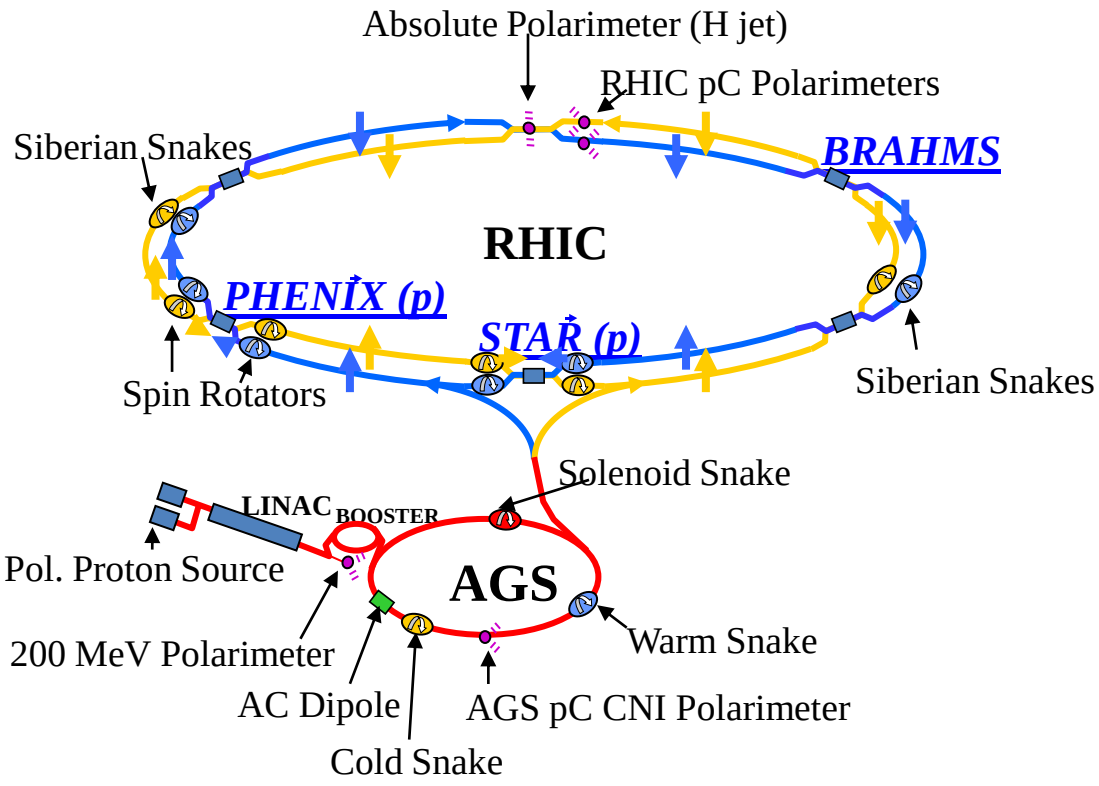
Polarized PDFs such as Δg

Fragmentation function for c → C, measured in e^+e^-

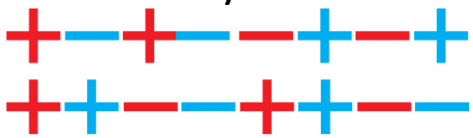
Partonic cross-section, calculated in pQCD

- Studying these requires a collider with polarized beam (i.e. RHIC)

RHIC



- Within 424 ns, all four possible bunch patterns: Reduces systematic uncertainty



- Siberian snakes rotate spin orientation so that on average, depolarizing perturbations cancel on subsequent passes (and polarization is retained)
- Spin Rotators allow polarization to be changed from vert. to long. in interaction region

Double Longitudinal Spin Asymmetries

- We can study differences in cross sections through "double longitudinal spin asymmetries" or A_{LL}s:

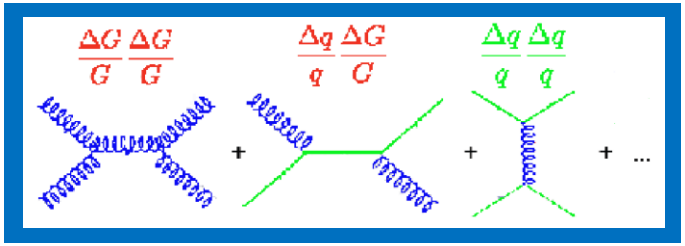
$$A_{LL} \equiv \frac{\{d\sigma_{++} + d\sigma_{--}\} - \{d\sigma_{+-} + d\sigma_{-+}\}}{\{d\sigma_{++} + d\sigma_{--}\} + \{d\sigma_{+-} + d\sigma_{-+}\}} = \frac{d\Delta\sigma}{d\sigma}$$

like helicity collisions — un-like helicity collisions

- Which, assuming factorization, is like

$$A_{LL} \approx a_{gg}\Delta g^2 + b_{gq}\Delta g\Delta q + c_{qq}\Delta q^2$$

process and kinematic dependent



- And in terms of observables (particle yields N, polarizations P, relative luminosity R), reduces to

$$A_{LL} = \frac{1}{P_B P_Y}\frac{N^{++} - RN^{+-}}{N^{++} + RN^{+-}}, R = \frac{L^{++}}{L^{+-}}$$

Longitudinally Polarized p+p Runs @ PHENIX

Run (End Year)	√s (GEV)	L recorded (pb^{-1})	Polarization	FOM (P^4*L)
Run 03	200	0.35	27%	0.0019
Run 04	200	0.12	40%	0.0031
Run 05	200	3.4	49%	0.2
Run 06	200	7.5	57%	0.79
Run 06	**62.4**	**0.08**	**48%**	**0.0042**
Run 09	200	16	57%	1.5
Run 09	**500**	**14**	**39%**	**0.21**

In Run ending 2011, will significantly increase 500 GeV data set.
Current proposal calls for 50 pb^{-1} in 2011 (With the main goal being W-physics)
If reasonable polarization is achieved, will extend x reach of A_{LL}

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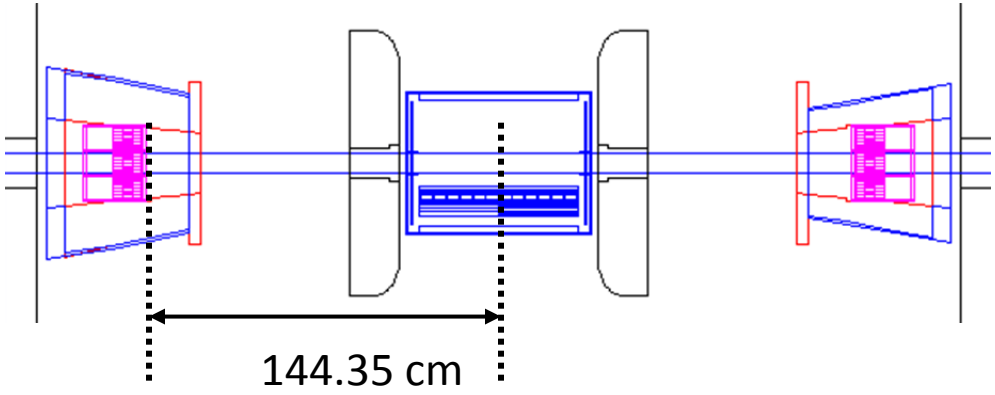
Relative Luminosity and Polarization

Beam-Beam Counters (BBCs)



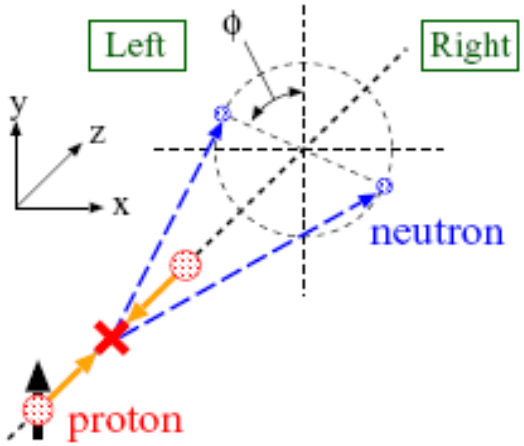
- Two arrays of 64 elements, each a quartz Cherenkov radiator with PMT
- $\Delta\eta = \pm(3.1 \text{ to } 3.9)$, $\Delta\phi = 2\pi$
- Used for relative luminosity measurement:

$$R = \frac{L^{++}}{L^{+-}} \approx \frac{N_{BBC}^{++}}{N_{BBC}^{+-}}$$

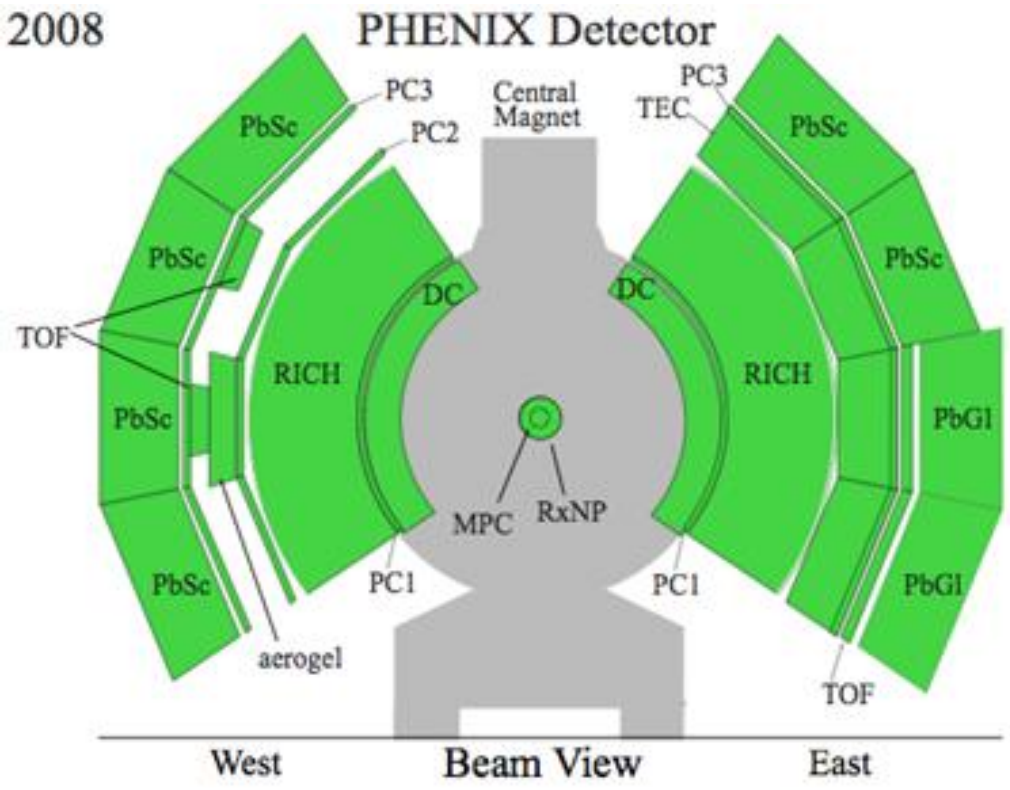
- Also, currently used to determine collision vertex

Local Polarimetry with the Zero Degree Calorimeters (ZDCs)

- ZDCs are hadron calorimeters
- They cover $\Delta\eta = \pm(6 \text{ to } \infty)$, $\Delta\phi = 2\pi$
- Large *transverse* single spin asymmetry has been measured in neutrons at very forward η
  - Use this: Smaller Left-Right or Up-Down asymmetry in ZDC = more long. polarized
- ZDC can also be used as cross-check for relative luminosity



PHENIX Central Arm



- $|\eta| < 0.375$, $\Delta\phi = (\pi/2) \times 2$

π^0, direct photon

- Electromagnetic Calorimeter (EMCal)
  - Lead Scintillator (PbSc) sampling calorimeter and Lead Glass (PbGl) Cherenkov radiator
  - Good timing, energy, and spatial resolution

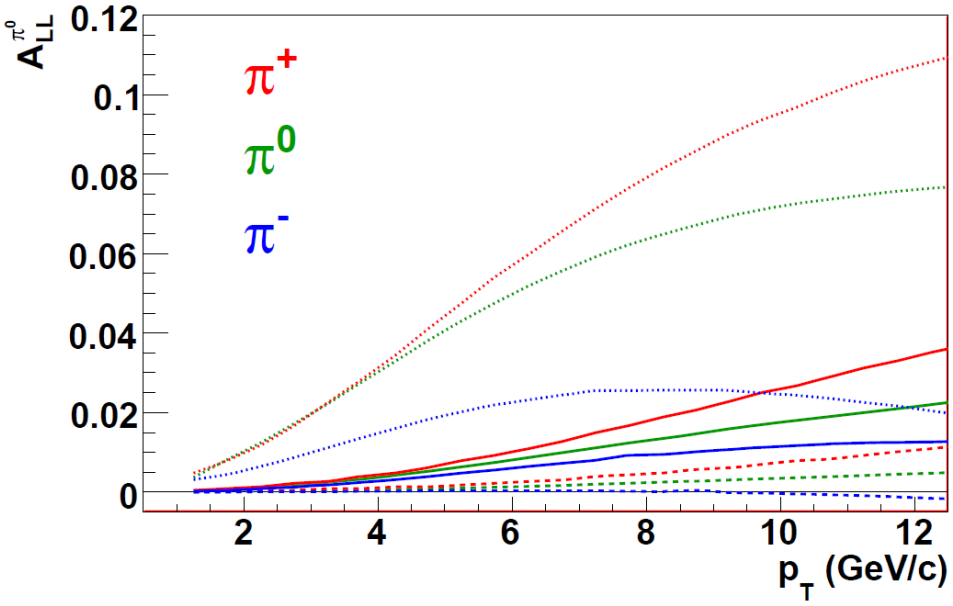
$\pi^{\pm}$

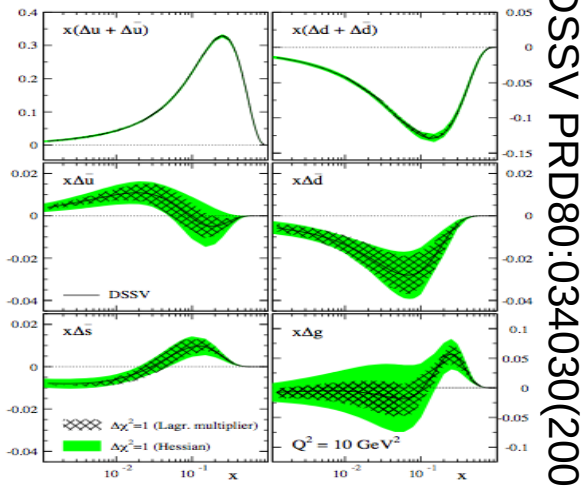
- Ring Imaging Cherenkov Radiator (RICH)
  - Particle identification
  - Pion threshold 4.7 GeV
- Drift Chamber (DC)
  - First step in charged particle tracking
  - High p_T resolution
- Pad Chamber (PC)
  - 3 layers of multiwire proportional chambers
  - Additional points for tracking

A_{LL}: Charged Pions

Analysis:

- Select π± (and background e±) with the RICH
  - 4.7 GeV/c turn-on
- Remove non-conversion e± with e/p and other cuts
- Conversion electrons removed by comparing vertex with DC track, PC, EMCAL





DSSV PRD80:034030(2009)

- Preferential fragmentation of
  - u quarks into π^+
  - d quarks into π^-
- A_{LL}s for π^-, π^0, π^- should be ordered depending on sgn(ΔG)
  - Could be complicated by node in Δg

$$A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-} \Rightarrow \Delta G > 0$$

$$A_{LL}^{\pi^+} < A_{LL}^{\pi^0} < A_{LL}^{\pi^-} \Rightarrow \Delta G < 0$$

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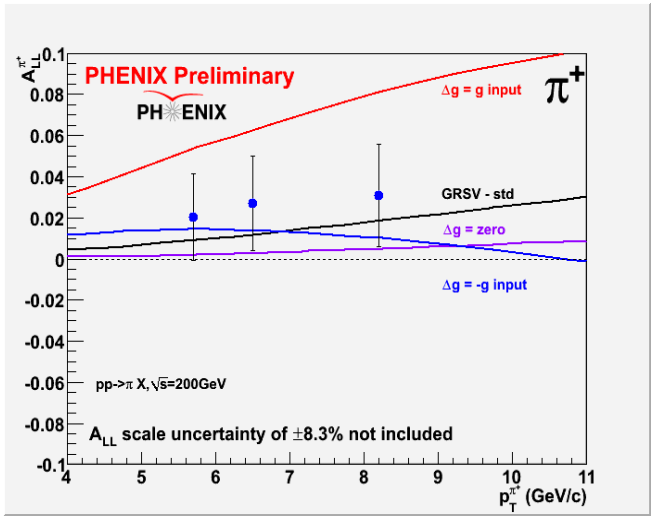
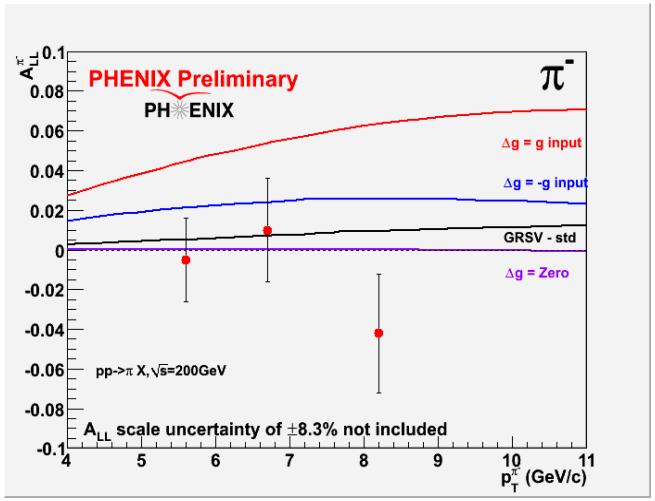
A_{LL}: Charged Pions

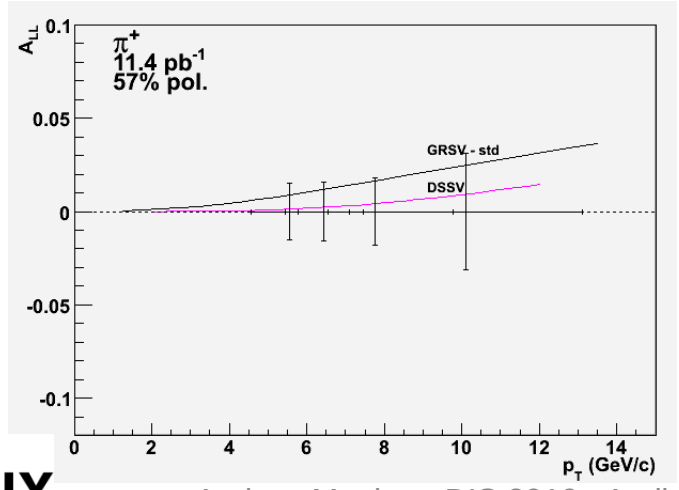
- Run 06 Results
- Run 09 data analysis ongoing
  - Figure of Merit, P^4L, was 0.79 pb^{-1} for Run 06
  - vs. 1.5 pb^{-1} for Run 09

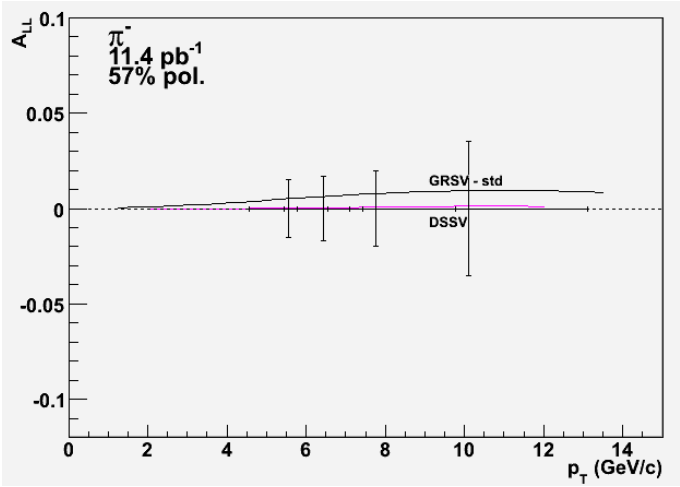
Run 06 Results:





Run 09 Uncertainty Projection:

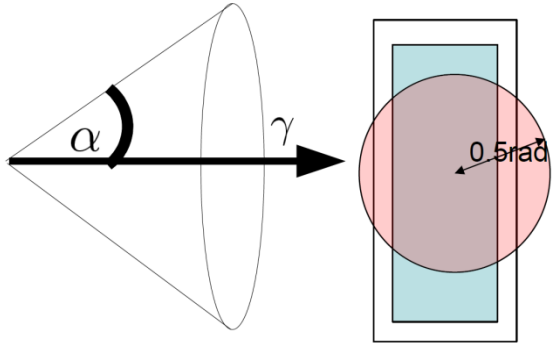




A_{LL}: Direct Photon

- Quark-gluon Compton scattering dominates
  - Linear in ΔG
  - Theoretically clean

→ A "Golden Channel"

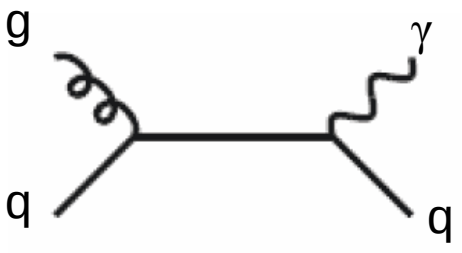


Analysis:

- Isolation cut for direct photon candidates
- Large decay photon BG

  →Cut partners with π^0 mass
- Miss some:

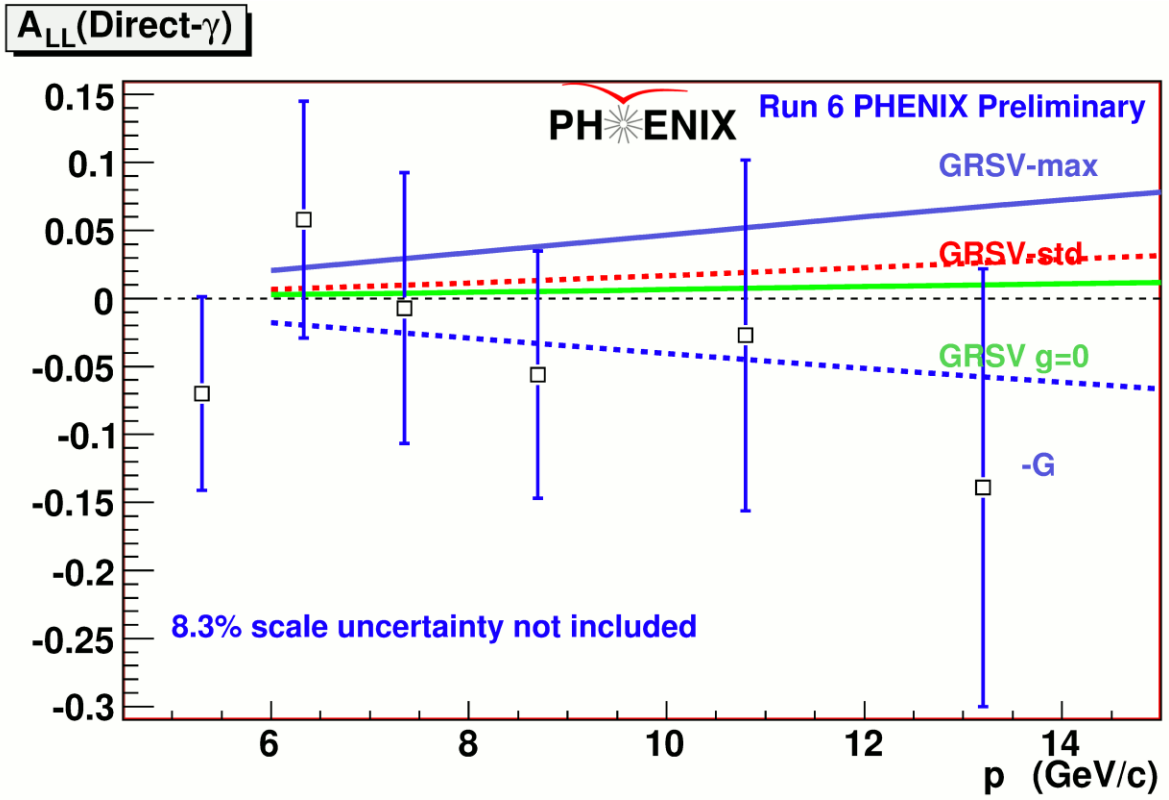
  →Estimate from number cut with Monte Carlo



$$r = N^{BG}/N^{iso}$$

Bin p_T	r
5-6	0.68
6-7	0.58
7-8	0.46
8-10	0.34

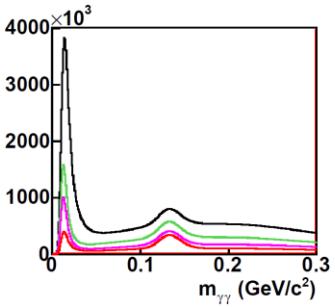
A_{LL}: Direct Photon



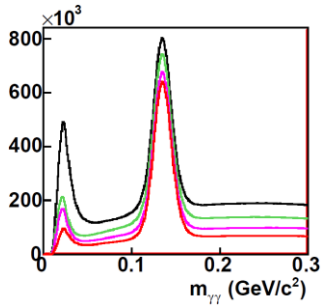
- First measurement
- Run 09 data analysis ongoing

A_{LL}: Neutral Pion

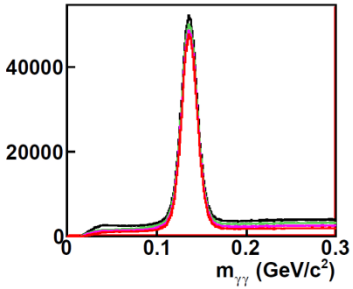
- High statistics measurement
- Gluon-gluon dominated, significantly constrains magnitude of ΔG



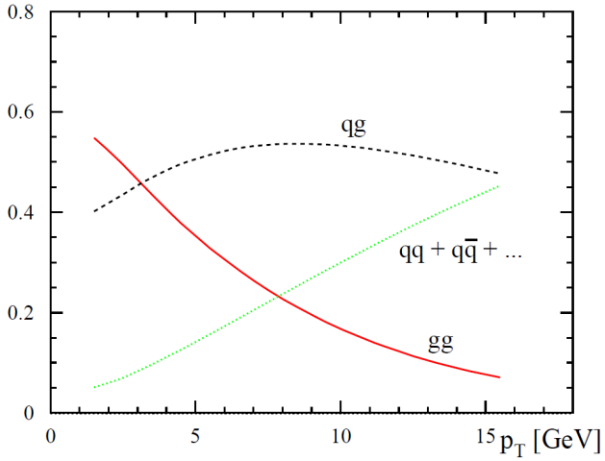
p_T 1-1.5 GeV



p_T 2-2.5 GeV



p_T 4-5 GeV

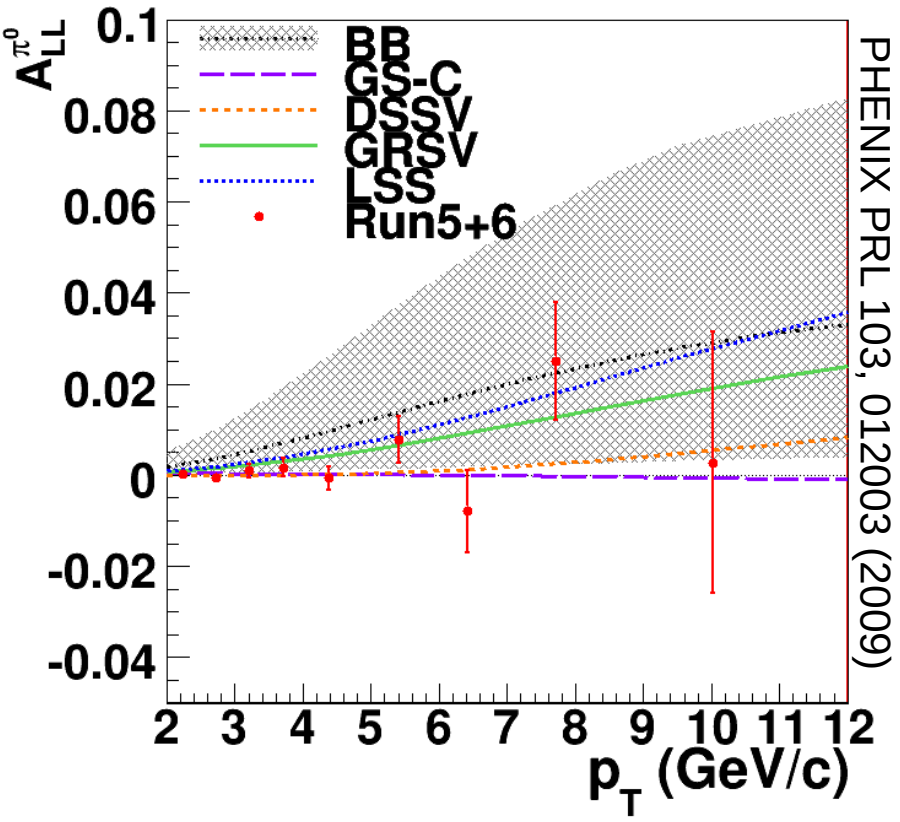


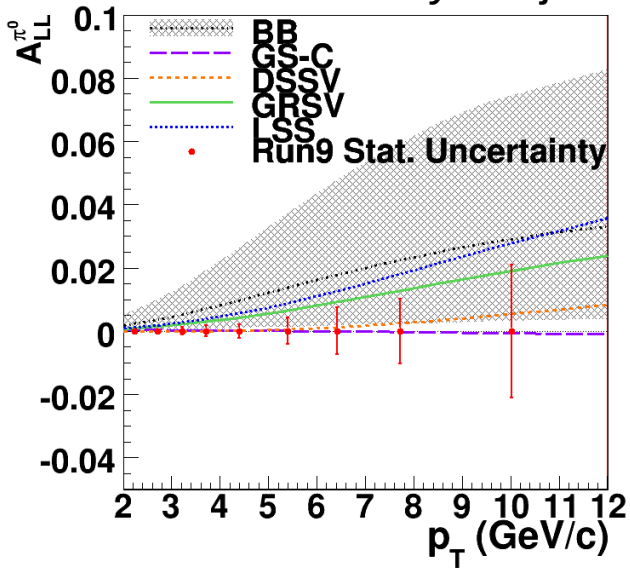
Analysis:

- Pair all photons in EMCal to reconstruct mass
- Various cuts to remove hadrons and noise
- Remaining combinatorial and other BG contribution estimated using sidebands

A_{LL}: Neutral Pion @ 200 GeV

200 GeV Run 05 + 06 results and Run 09 Statistical Uncertainty Projection





Run (Yr)	(<P_B>,<P_Y>)(%)	$L_{analyzed}$ (pb^{-1})	FOM (P^4*L)
'05	(50,49)	2.5	0.15
'06	(56,57)	6.5	0.66
'09	~(57,57)	~14	~1.5

- Runs 05, 06 and 09 results can be combined
- Systematics important in Run 09 and beyond:
  - Double collisions effect Lumi counting, z-vertex determination with the BBC
  - EMCal response at high rate

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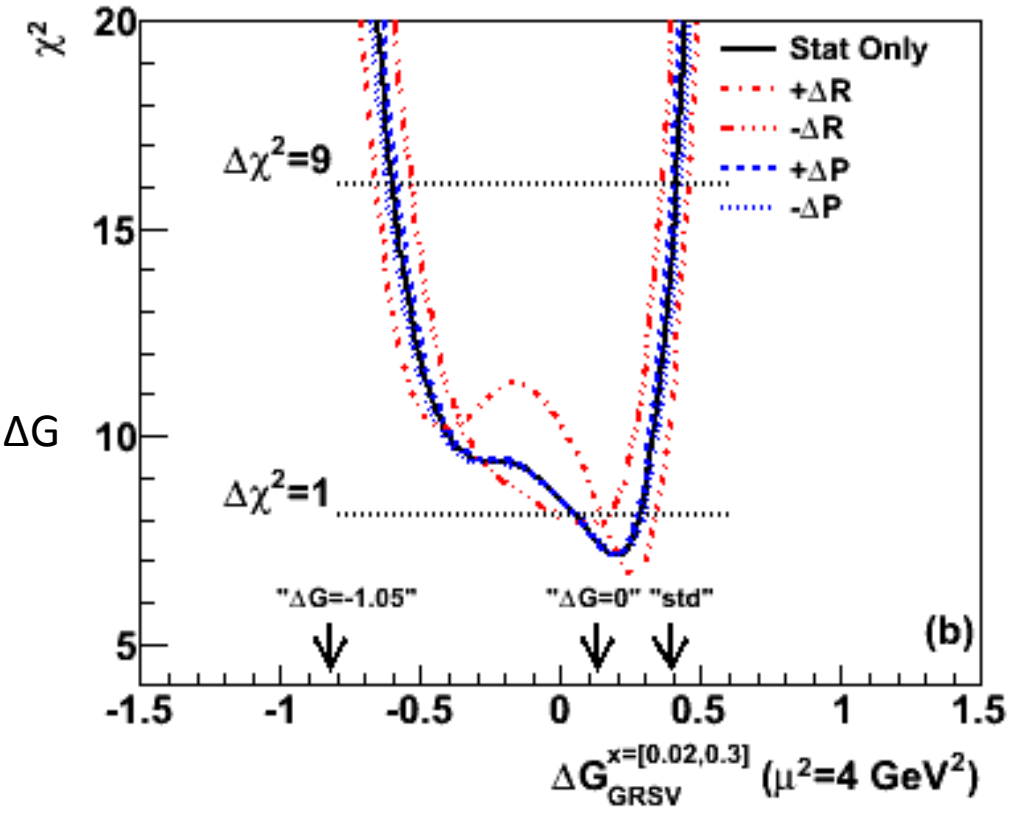
Constraining ΔG

- From the π^0 result

For statistical and systematic uncertainties,

- Run 05 + Run 06 π^0 A_{LL} data
  compared with
- GRSV fit to DIS data with various ΔG as input
  -> Generate χ^2 plot

- Theoretical uncertainties:
  - Shape of Δg (parameterization)
  - Energy scales (factorization, fragmentation, renormalization)



Significant constraint on ΔG

$$\Delta G^{[0.02,0.3]}_{\mathrm{GRSV}} = 0.2 \pm 0.1(\mathrm{stat}) \pm 0.1(\mathrm{sys}) {}^{+0.0}_{-0.4}(\mathrm{shape}) \pm 0.1(\mathrm{scale})$$

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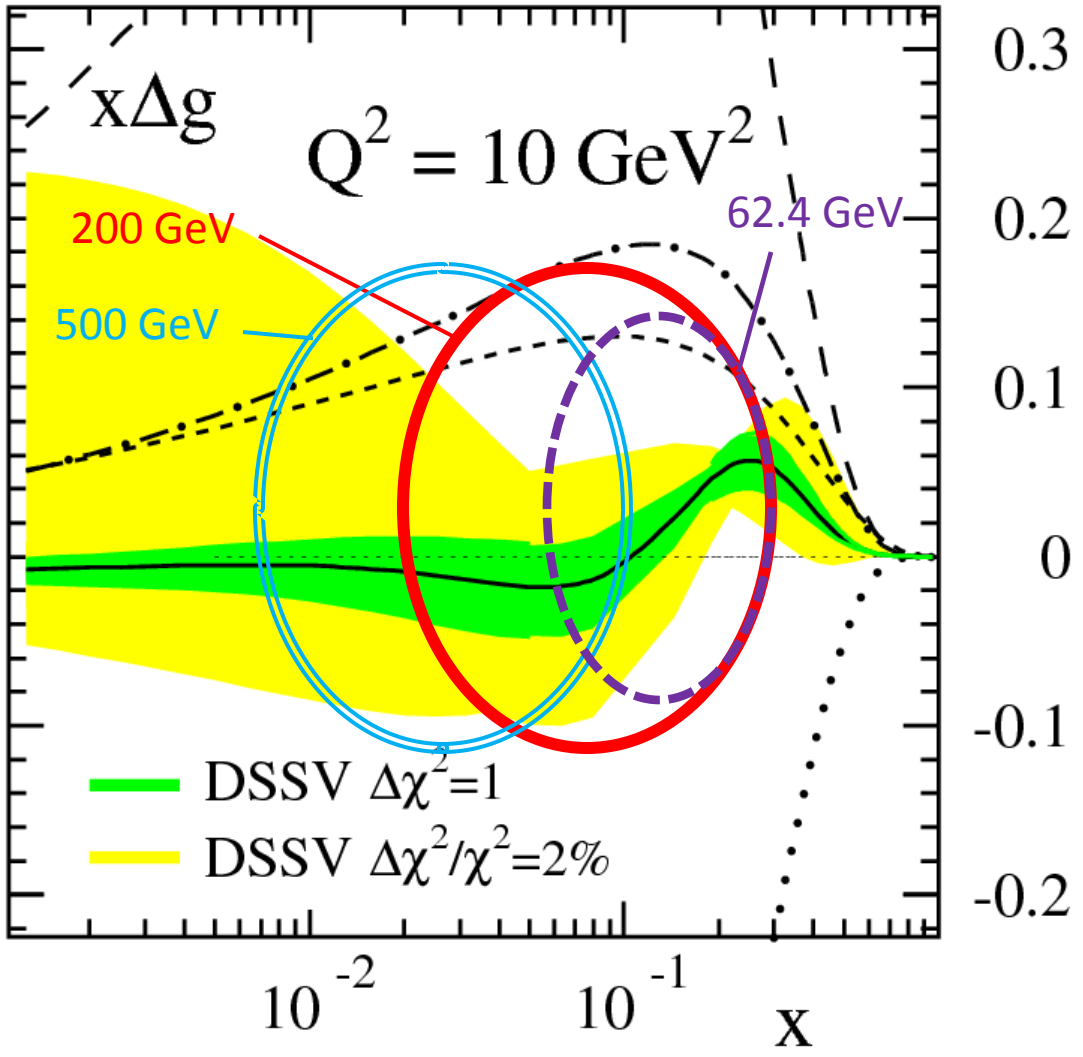
DSSV global fit

- NLO global analysis
- By de Florian, Sassot, Stratmann, and Vogelsang
- Uses DIS, SDIS, PHENIX and STAR data
- Run9:
  - 200 GeV impact significantly higher than Run6
  - 500 GeV will push the constraint to lower x
- 62.4 GeV gives better statistics for higher x

Phys.Rev.Lett.101:072001,2008



Conclusion

- Multiple Channels to measure ΔG with double longitudinal spin asymmetries
  - π^0 A_{LL} significantly constrains ΔG
  - 500 GeV data will extend reach
  - Other channels will benefit from increased statistics (i.e. Run 09 analyses underway)
- PHENIX data is already being used in global analysis (DSSV)

Backup

More A_{LL}s

- Other Channels:
  - Jet components (q+q, q+g, g+g):
    - η (similar to , $h^{\pm}$, jet, (also $\pi^{\pm}$, π^{0})
  - Direct Photon (q+g)
  - Heavy particle (g+g)
    - Open charm to e, μ
    - Open bottom: J/ψ to e+e, μ+μ